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# Network Planning Aspects of DS-CDMA with Particular Emphasis on Soft Handoff

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**Abstract**—In this paper, a study into the application of soft handoff in wideband Direct Sequence Multiple Access Communications systems (DS-CDMA) is described. Soft handoff is explained in terms of macroscopic diversity, a form of diversity combining in which signals transmitted via independently fading paths can be combined in order to enhance the overall performance. Results from a series of outdoor propagation studies, specifically designed to investigate the propagation aspects of soft handoff are presented and the future work activities of the project are outlined.

## I. INTRODUCTION

Radio standards committees throughout the world are currently considering the third generation of mobile services. In Europe the European Telecommunications Standards Institute (ETSI), is currently defining the Universal Mobile Telecommunications System (UMTS). UMTS intends to provide, in addition to audio telephony, a wide range of high quality data services not available through current second generation systems, such as GSM in Europe and IS-54 in the USA. These services are expected to include, for example, video conferencing and high speed data transfer at up to 2Mb/s.

DS-CDMA has been proposed as a possible contender as the access technique for UMTS alongside TDMA [1]. It is therefore necessary to consider whether the appropriate planning tools exist for the successful deployment of such a system. DS-CDMA networks can potentially offer complete frequency re-use, therefore frequency planning is not deemed a critical aspect of the system design, unless the proposed spectrum allocation for UMTS is channelised. It has, however, been shown that the optimum implementation of techniques such as soft handoff, can enhance both the capacity and the quality of service provided by DS-CDMA [2]. Thus, it is essential to develop a better understanding of this form of macroscopic diversity, in order to develop the necessary planning tools for DS-CDMA networks.

## II. MACROSCOPIC DIVERSITY

In a cellular environment, signal strength variations can occur due to the shadowing effects of the surrounding buildings, vehicles and other geographical features. Macroscopic diversity is a technique whereby transmissions from the same mobile station are received at different base stations and then used to establish the best communications link. This can also apply to the downlink with

the mobile combining the signals transmitted from two or more base stations [3].

In order that a diversity combining technique can be used to any degree of efficiency, the different transmission paths used must exhibit independent fading characteristics. Macroscopic diversity relies on the principle of diversity combining, whereby the use of separate base stations to transmit and receive the same call ensures uncorrelated signal paths [4].

Macroscopic diversity can be used to enhance the overall performance of a communications link with respect to signal strength (for DS-CDMA this reduces the required  $E_b/N_0$  to support a given error rate) and signal-to-interference ratio for an interference limited system. It has been shown that macroscopic diversity can reduce the link margin required for a 99-percent reliability system by as much as 10dB [5].

Macroscopic diversity dates from the 1920's, but more recently it has been associated with modern mobile communications systems such as UMTS. Interference limited systems such as DS-CDMA can utilise this form of spatial diversity to provide a system feature known as "soft handoff", thus enhancing the quality of service offered by the network.

In a cellular environment employing soft handoff, a mobile unit will constantly monitor the signal strength from nearby base stations. The unit will select the best communications paths to maintain an optimum signal quality. As the mobile approaches a cell boundary, a link will be established with another base station in a neighbouring cell. The call is now carried by two, or possibly more, base stations. At the mobile station, the signals received from each of the base stations are combined. Whilst for the uplink, the signals received at either base station would be sent to the Mobile Switching Centre (MSC), with an additional signal weighting related to the received signal quality. The MSC decides which of the signals to use to maintain optimum signal quality. This process will continue until the user is firmly established in the new cell, at which point the old base station will be instructed to discontinue carrying the call.

By careful allocation of the soft handoff region and its associated parameters for operation, the "Ping-Pong" effect (constant handing back and forth between base stations) common with hard handoff, is thus avoided. This is as a consequence of a "make before break" rather than "break before make" handoff between base stations, giving a lower probability of dropped calls due to the actual handoff process.

### III. DIVERSITY COMBINING

Uncorrelated signals may be beneficially combined by several techniques. Amongst these are Selection Diversity, Maximal Ratio Combining and Equal Gain Combining.

Selection Diversity is the simplest method, whereby the diversity branch with the strongest signal-to-noise ratio is selected as the one to be used by the system.

Maximal Ratio Combining necessitates the use of co-phased signals within the receiver, before combination. Each branch is then given a gain weighting according to its signal-to-noise ratio before the signals are summed.

A simpler system to that of Maximal Ratio Combining is that of Equal Gain Combining, where each diversity branch is given an equal gain weighting of unity, irrespective of the signal power received, before summing.

### IV. MEASUREMENT SYSTEM DESCRIPTION

In order to produce a network planning tool for soft handoff, it is necessary to study the propagation phenomena which occur during the handoff region of a typical cellular environment. To date the majority of propagation studies for mobile radio, are concerned with the conventional large macrocells (radius > 1km), although a few studies now exist for environments more akin to the expected microcellular structures within a Third Generation System [6]. Therefore, a series of propagation measurements were required to provide the data for soft handoff analysis.

The propagation measurements were performed using a wideband correlation type channel sounding system [7], operating close to the allocated frequency band of the Future Public Land Mobile Telecommunications System (FPLMTS), 1885MHz to 2025MHz. The system comprises two base station transmitters and a single mobile dual channel receiver. The base stations are distinguished by unique pseudo-random binary sequences (PRBS).

#### A. The Channel Sounder

Figure 1 shows the block diagram of one of the transmitters used for the propagation work operating at a centre frequency of 1.87GHz. Each wideband transmitter operates using one of a preferred-pair, 511 bit maximal, or M-length PRBS, to bi-phase modulate the 1.87GHz carrier. The sequence is clocked or "chipped" at 20MHz, giving the channel sounder an echo resolution of 50ns - an equivalent distance or path length of about 15 metres. This will also give the sequence a repetition time of 25.55µs and an observable maximum excess path length of 7.66km. By using a preferred pair code it is possible to simultaneously receive and distinguish between the signals from either transmitter, with a minimum cross-correlation between the two codes. (The channel sounder was originally designed to provide chipping rates of 20, 10, 5, 2.5 or 1.25Mb/s and produce PN sequences of length 255, 511, 1023 or 2047 bits, although only the 511 bit sequences are currently implemented as a preferred pair code).

The receiver operates as a dual, time slip correlation receiver, as shown in Figure 2. The received signals are filtered and amplified before mixing down to a 70MHz IF. The correlation process is performed in quadrature by clocking an identical sequence to that

of each transmitter but at a slightly different chipping rate. By combining the two codes at the same IF within the receiver, a complex channel impulse response is produced for each base station simultaneously.

The channel response data is output from the receiver unit as quadrature analogue information. These signals are then sampled and stored to disk, via an A/D card connected to a personal computer. The relative location of each data sampling position during the trials, was found using an external pulse generating source located on the vehicle. This source produces a single pulse every 1.25cm. Data was sampled at approximately every metre along the length of the measurement site. The quadrature information was stored along with the position of the vehicle relative to the transmitters.

#### B. Measurement Site.

The location for an initial study of soft handoff was chosen such that it was representative of a microcellular environment. A map of the transmitter locations is shown in Figure 3. University Walk is a driveway located outside the Engineering Department at the University of Bristol. It is flanked on one side by a 2.8 metre high stone wall, whilst the other side is lined by University buildings and car parks. The roadway used for the trials consists of two stretches, with a bend at approximately 180 metres from the first base station and 80 metres from the second base station. The vehicle containing the receiver was driven along the road between the two. The base station antennas were mounted on lampposts, just below the height of the stone wall, whilst the receiver antenna was mounted on the vehicle roof.

### V. EXPERIMENTAL RESULTS AND DISCUSSIONS

Channel sounding measurements were taken along the section of University Walk shown in Figure 3, using the equipment described in Section IV. The vehicle speed throughout the measurements was kept low (<2km/h) to enable channel impulse response readings to be taken at approximately every metre. The data obtained from these readings was then stored to disk. Prior to the start of the trials, the power levels for each transmitter were adjusted so that the received signal strength from each was approximately equal at the point A shown on Figure 3. At this location there was no line of sight path (NLOS) to either transmitter.

A series of trials were performed along the same route and the results from these trials were later analysed. Figure 4 shows the relative received peak signal-to-noise ratio for each transmitter along the length of the section of University Walk. It can be seen that the signal strengths converge after a distance of 70 to 80 metres from the start, which coincides with the bend in the road after which Line of Sight (LOS) with either transmitter would be lost. For the microcellular environment under study, the 10dB power window was found to be approximately 70ns.

At the bend in the road, there is a rapid degradation in signal strength from the first base station and a matching rise in signal from the second base station. This observation is in line with those made by Chia [8] and Lotze [9], who have experimentally found a signal degradations of 20-30dB within 10-20 metres of street corners. It is within this region that a handoff would be expected to be instigated. Shown on Figure 4, is an arbitrary 6dB window to

demonstrate a possible handoff scenario. The two threshold levels  $T\_ADD$  and  $T\_DROP$  are used to indicate the points at which soft handoff operations would be initiated on entering the new cell and where the handoff operation would be terminated as the mobile leaves the old cell, respectively. This is based on the soft handoff procedures described by Qualcomm [10]. Several potential problem areas can be identified in the use of such a window in this environment.

The threshold levels  $T\_ADD$  and  $T\_DROP$  are frequently crossed by both signals and if this were a plot of the pilot signals received from either base station in a soft handoff system, then the speed of the mobile user and the timing specifications of the system are critical to the success of the handoff [11]. For example, if there was a slow or stationary mobile user at these locations, the time over which these threshold transitions occur, may exceed the timer limit of the system and cause premature termination signals to be sent to the base stations concerned, leading to unnecessary handoffs or even a dropped call.

As mentioned in Section II, the reliability of a diversity combining technique is dependent on the amount of de-correlation between the individual diversity branches, which in this case corresponds to the signals received from the two base stations. Figure 5 shows a scatter plot of the relative received signals at any point of University Walk where simultaneous reception from both base stations was possible. Data from three trials has been used and the overall cross correlation factor was found to be 0.1677, implying very decorrelated fading characteristics from each base station.

The impact of diversity combining is illustrated in Figure 6. This plot shows the received signals from each base station over the soft handoff region, along with a diversity combined signal. The combined signal is achieved by using a combination of selection diversity and equal gain combining. Only when it was possible to receive a significant signal level from both base stations above a set noise threshold, were the signal magnitudes added together to produce the combined signal. Otherwise the combined signal was taken as being the stronger of the two received signals. This resulted in a signal which has a theoretical maximum gain of 6dB over either received signal. In a soft handoff system the base stations would be required to transmit less power in order to maintain the same combined signal strength at the mobile as for individual base stations. The reduction in transmitted power from either base station reduces the noise within the system, and so could potentially increase the overall capacity for an interference limited system, such as DS-CDMA.

## VI. CONCLUSIONS

The results presented have been used to illustrate some of the considerations necessary in order to successfully implement the macroscopic diversity technique known as soft handoff. This can be of benefit to an interference limited system, such as DS-CDMA. In the planning of a network incorporating soft handoff, careful planning of the handoff regions with respect to their size and the timing specifications have to be given to prevent unnecessary signalling and handoff within the network. Both of which affect the ultimate capacity of the system and the signal quality.

The future aims of the project are to study the effects on overall system quality and capacity through the use of soft handoff. It is

also expected to study the actual mechanism of the soft handoff protocol within the system and compare this to hard handoff systems currently in operation. Other measurement studies will include alternative microcellular environments, as well as considering the power control and signalling aspects involved. The data obtained from these further studies will be used to develop network planning tools for use in a UMTS system.

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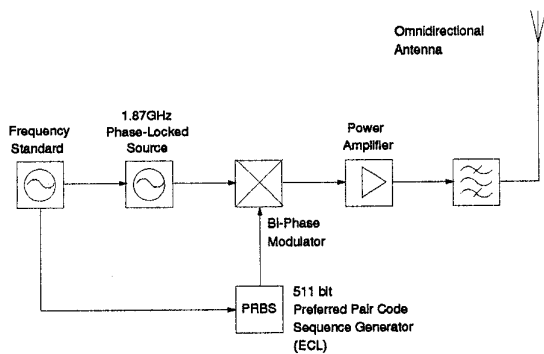


Figure 1. Channel Sounder Transmitter.

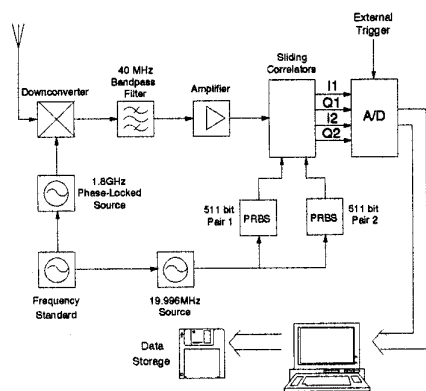


Figure 2. Channel Sounder Receiver.

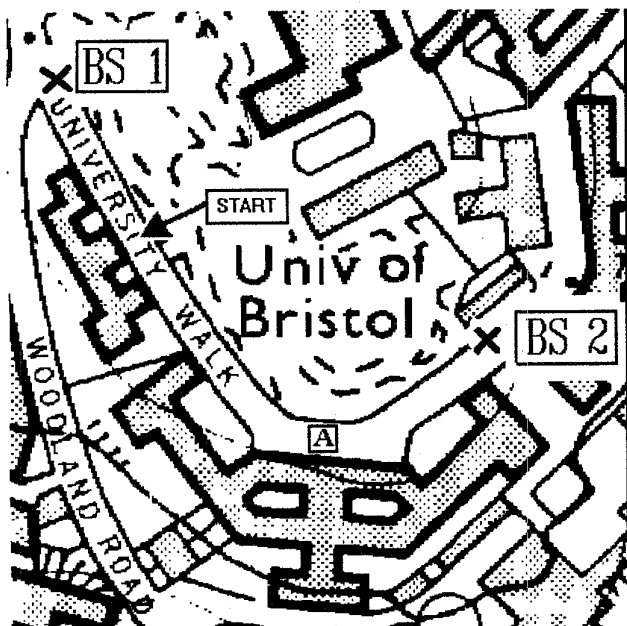


Figure 3. Location of Base Stations on University Walk

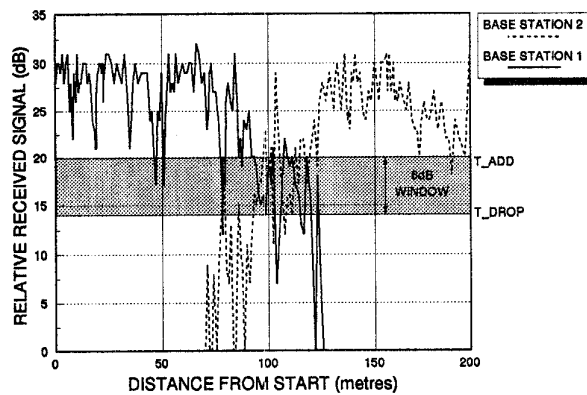


Figure 4. Peak Signal to Noise Versus Distance.

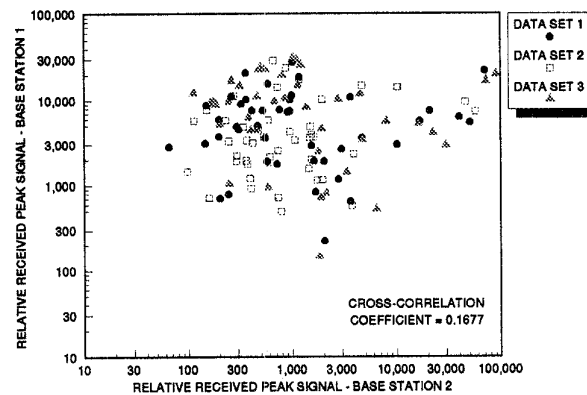


Figure 5. Scatter Plot of Base Station Signal Strengths.

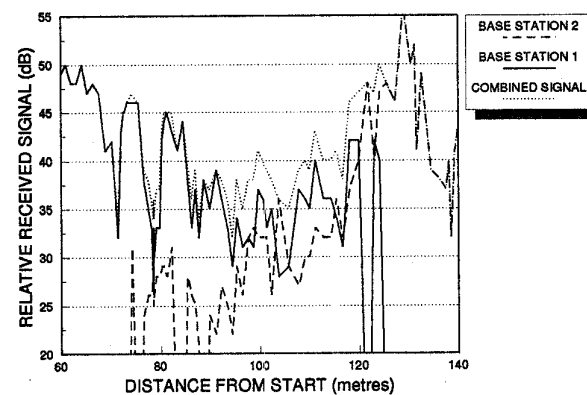


Figure 6. Diversity Combined Signal from two Base Stations.